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(NASA-CR-150465) NUCLEONIC COAL DETECTOR
WITH INDEPENDENT, HYDROPNEUMATIC SUSPENSION
Final Report (Mississippi State Univ.,
Mississippi State.) 49 p HC A03/MF A01

N78-11454

Unclas
CSCL 08I G3/43 53534

NUCLEONIC COAL DETECTOR
WITH
INDEPENDENT, HYDROPNEUMATIC SUSPENSION

(FINAL REPORT)

for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, AL 35812

Contract No. NAS8-32214

by

E. William Jones, Ph.D., P.E., Principal Investigator
Kim Handy

Mechanical Engineering Department
Mississippi State University
Mississippi State, MS 39762

June 1, 1977



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ABSTRACT

The design of a nucleonic, coal interface detector which measures the depth of coal on the roof and floor of a coal mine is presented. The nucleonic source and the nucleonic detector are on independent hydropneumatic suspensions to reduce the measurement errors due to air gap. This project is one component of a NASA program for the Bureau of Mines concerning the automation of the Longwall Shearer.

CHAPTER 1

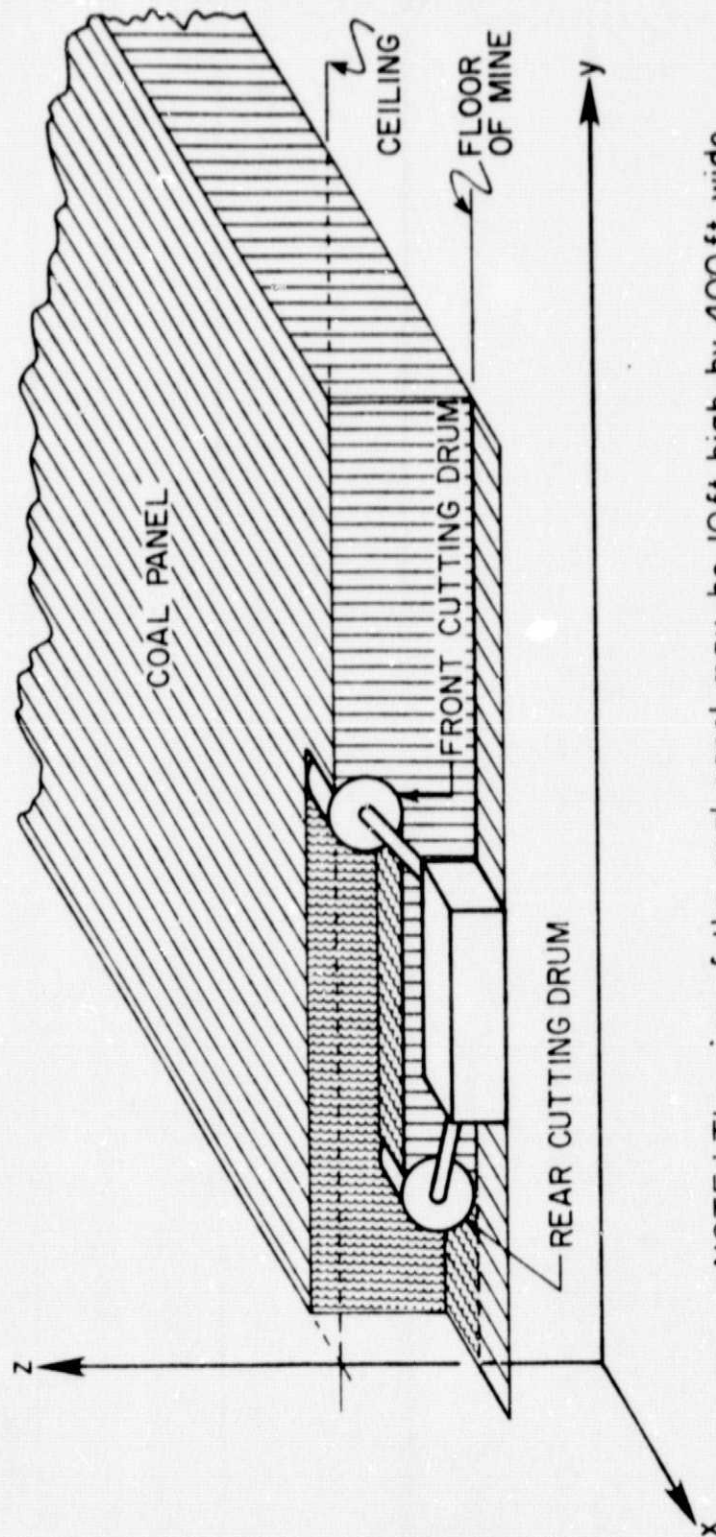
INTRODUCTION

One proposal for increasing coal production and improving mine safety is to automate the Longwall Shearer, LWS, [9]*. NASA engineers at the Marshall Space Flight Center are working on the automation of the LWS mining system for the Bureau of Mines, BOM. The operation of a Longwall Shearer cutting across the face of a coal panel is illustrated in Figure 1.1.

An instrument which continually measures the thickness of coal on the roof (and floor) of the mine is needed to improve operation of the LWS. This instrument could be used when it is desired to leave several inches of coal on a roof to prevent cave-in of loose roof materials. It could be used to prevent the shearing picks from continuously cutting into a rock roof. It could also be used to leave noncommercial quality coal on the mine surfaces. If the LWS is to be automated, this instrument could be used to guide the LWS along the undulating coal seam. Currently, the positions of the cutting drums for most LWS are guided by operators who walk beside the machine.

One of the current methods for measuring the thickness of coal covering a mine roof is a nucleonic instrument. This instrument emits gamma rays and then measures the intensity of the backscattered rays which reflect from the coal-rock interface. NASA [8] reports some errors in measurements with a similar device when variable air gaps existed between the coal surface and the instrument contact surface.

* Numbers in brackets refer to references.



NOTE: The size of the coal panel may be 10 ft high by 400 ft wide and 1000 ft long. Conveyor for transporting coal is not shown.

Figure 1.1. Longwall Shearer in Operation

This report describes the design of a nucleonic coal interface detector, CID, with adjustable separation between the nucleonic source and the detector and with independent hydropneumatic suspension of the source and the detector. This new CID is shown on a LWS in Figure 1.2. This design will be used to compare the nucleonic CID with other viable CID concepts.

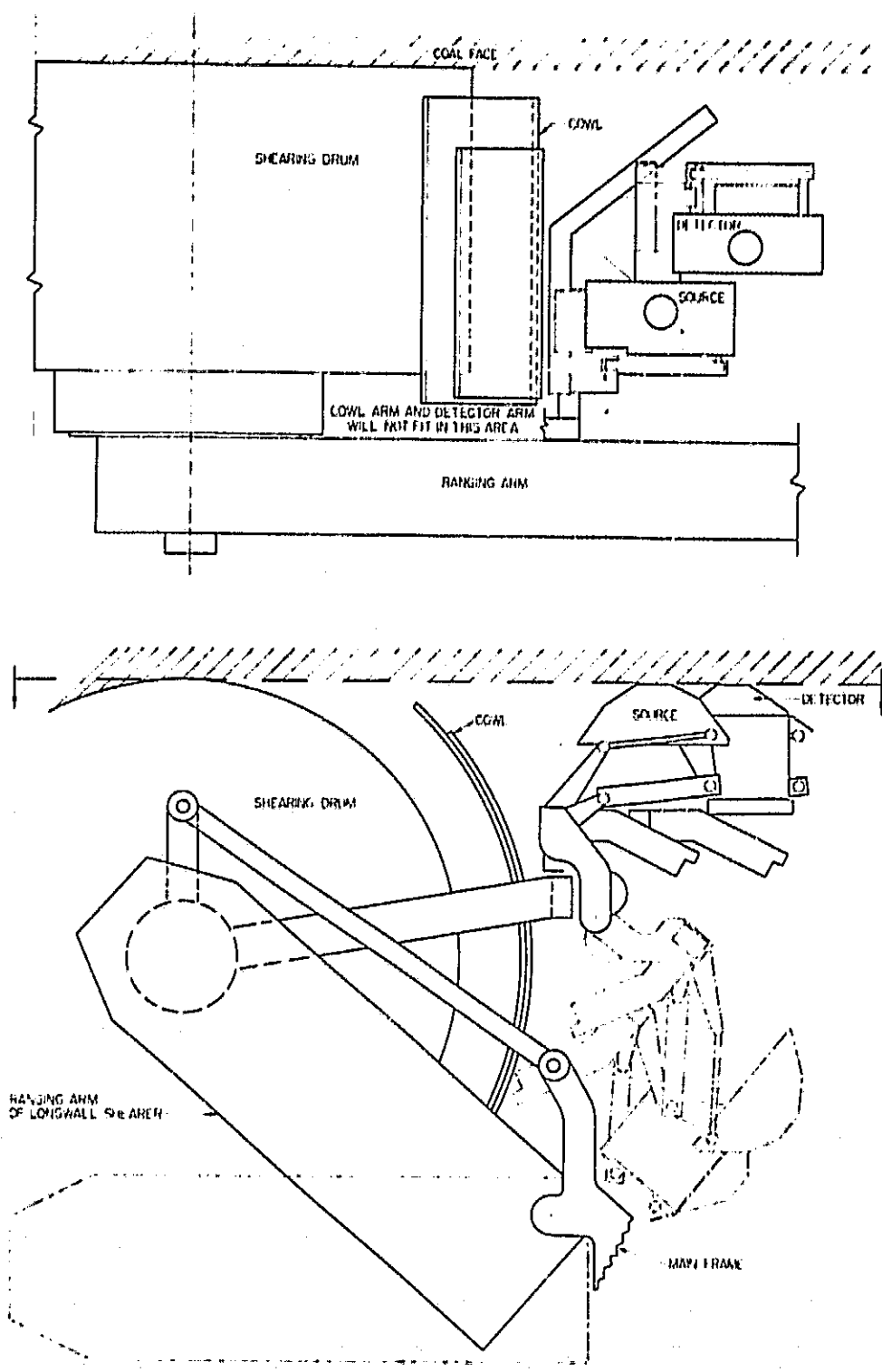


Figure 1.2. CID Positioned on Longwall Shearer

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CHAPTER 2

DESIGN OBJECTIVES

- 2.01 A Cesium 137 radiation source is to be used.
- 2.02 This source is to be enclosed in a housing which is to be independently suspended.
- 2.03 This source is to be enclosed by a 2.5 inch thick lead wall when in the "inactive" (i.e., safe or stored) position.
- 2.04 The radiation from the source is to pass thru an open .375 inch diameter by 1.0 inch long collimation hole prior to entering the coal surface. This occurs when the source is in the "active" position.
- 2.05 The centers of the radiation paths which leave the source and enter the detector are to intersect at an angle of 50 degrees. Each path is to be inclined 20 degrees from the vertical.
- 2.06 The source is to automatically rotate into the inactive position when the housing is not in contact with the coal surface. The source is to automatically rotate into the active position when the housing contacts the coal surface.
- 2.07 The position of the source (i.e., active or inactive) is to be identified by the position of a lever (i.e., a flag) on the source housing and by signal lights on the LWS.
- 2.08 The desired separation distances between source and detector were to be 7, 12, 17 and 22 inches. However, the final design provides separation distances from 10.5 to 22.5 inches in 2 inch increments.
- 2.09 The nucleonic detector is to be the Scintillation Detector by EMR Photoelectric. The 1.5 inch entrance tube is to be encircled by a 3 inch diameter lead cylinder.

- 2.10 The CID is to contact the coal surface at only two small surfaces in order to minimize the errors caused by variable length air gaps in the radiation path. These contact surfaces are at the openings for the radiation beam.
- 2.11 The opening out of the source and the opening into the detector are to be covered with .0625 and .125 inch thick polyurethane diaphragms to prevent debris from filling the openings. This .1875 inch thickness produces approximately 10% attenuation of the radiation signal.
- 2.12 The desired vertical movement of the source and detector housings relative to the shearing drum was to be ± 5 inches. However, the final design provides only ± 4.75 inches for the source.
- 2.13 A shear pin is to provide overload protection for the system in case of a roof cave-in.
- 2.14 The suspension systems for the source and detector must maintain contact between the housings and the coal at speeds up to 25 FPM. Figure 2.1 shows some typical roof profiles.
- 2.15 An electrical signal is to be provided which is proportional to the average vertical height of the two contact surfaces. (This may be an accelerometer inside of each housing.) Provisions for obtaining this signal are not shown on the layouts.
- 2.16 The CID must operate in the dusty, wet, hazardous conditions of a mine.
- 2.17 The CID must meet the Bureau of Mines Standard, Schedule 2G [1].
(This only applies to equipment for use in a mine.)
- 2.18 Hydraulic and electrical lines must be protected.

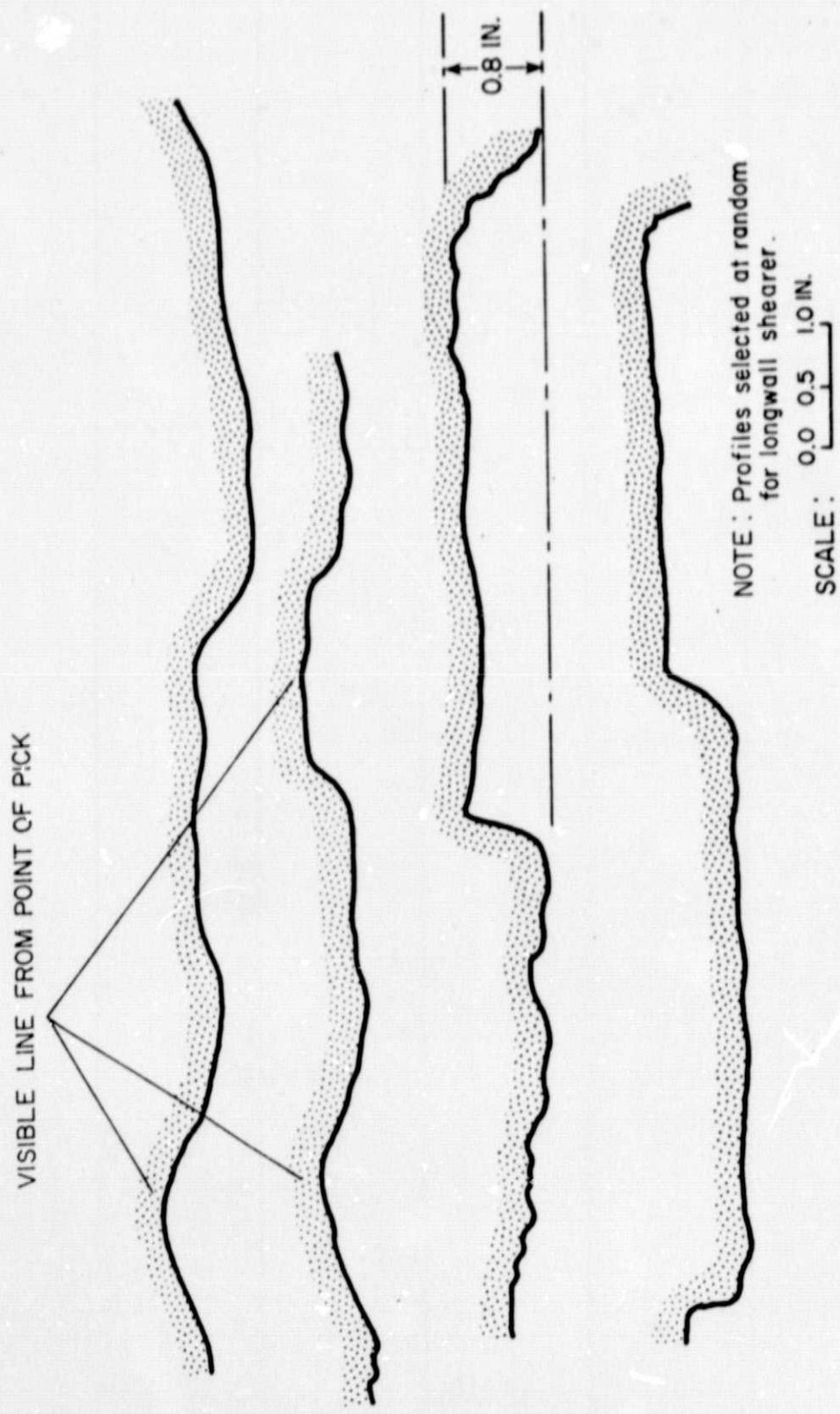


Figure 2.1. Typical Transverse Roof Profiles

CHAPTER 3

DISCUSSION OF THE DESIGN

A discussion of the final design and some of the significant alternate proposals are presented in this chapter. The final design is defined on layouts 010 thru 017 plus 019 thru 022. A general arrangement showing the side and top views of the source and the detector mounted on a LWS is shown in Figure 1.2.

The proposed mounting arm, which attaches the CID to the LWS, forms a parallelogram by using the LWS ranging arm. This parallelogram forces the CID to move thru the same distance as the shearing drum and in a direction perpendicular to the main frame of the LWS. The pivot for one link of this parallelogram is concentric with the cowl pivot per Figure 1.2. The source and detector housings are attached to this mounting arm by a suspension system.

Several suspension configurations were developed during this study. Figure 3.1 shows an independent suspension system with a single hydro-pneumatic spring plus a differential linkage system [8] (Layout 00A)**. Figure 3.2 shows a non-independent suspension system with coil springs (Layouts 001 thru 009). Figure 3.3 and Layouts 010-017 plus 019-022 show the independent suspension system with hydropneumatic springs [6] which represents the final design.

The hydropneumatic spring suspension system consists of an accumulator in series with two hydraulic cylinders which force the housings against

**

Layouts are described in Appendix C.

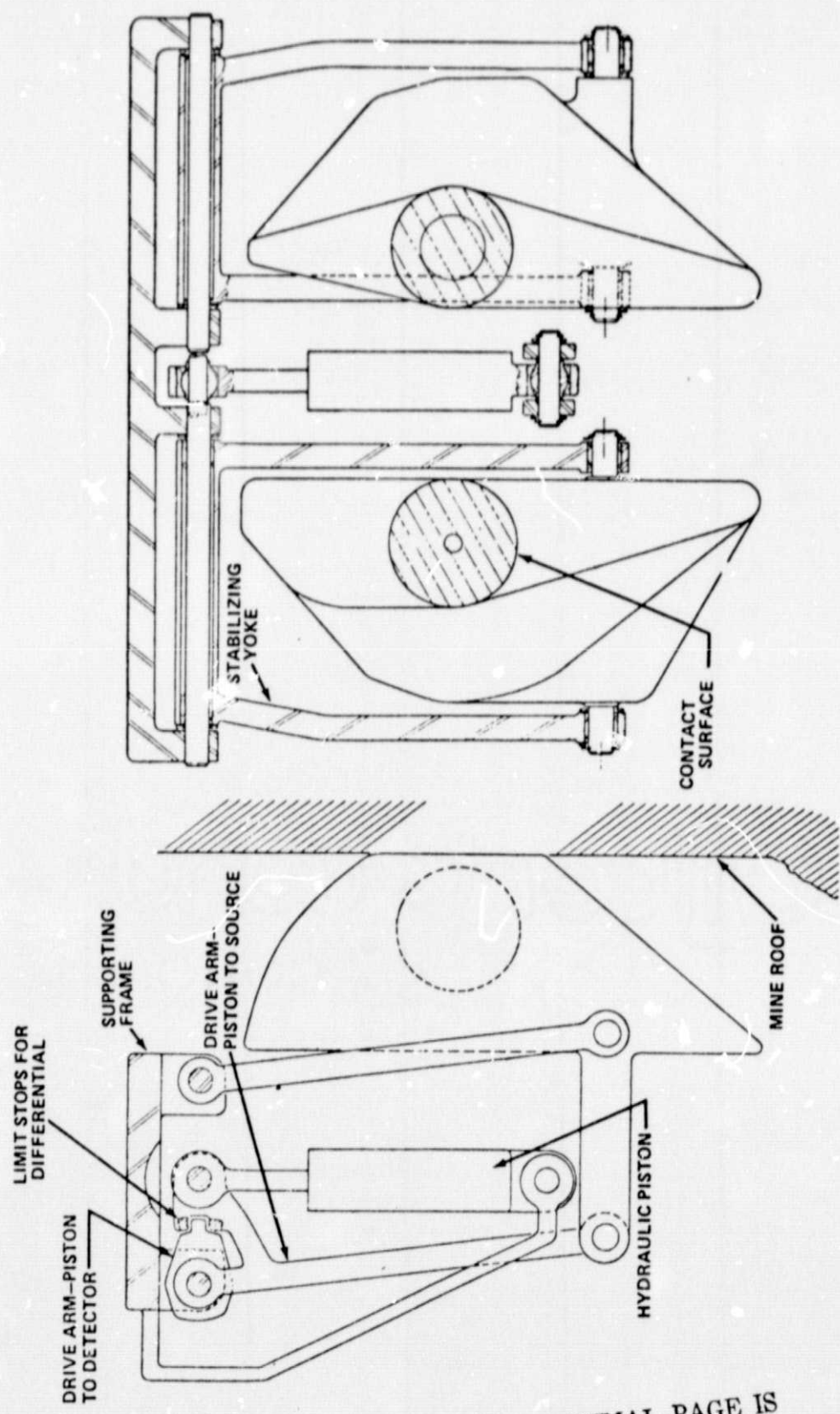


Figure 3.1. Nucleonic Sensor Suspension System with Differential Linkage

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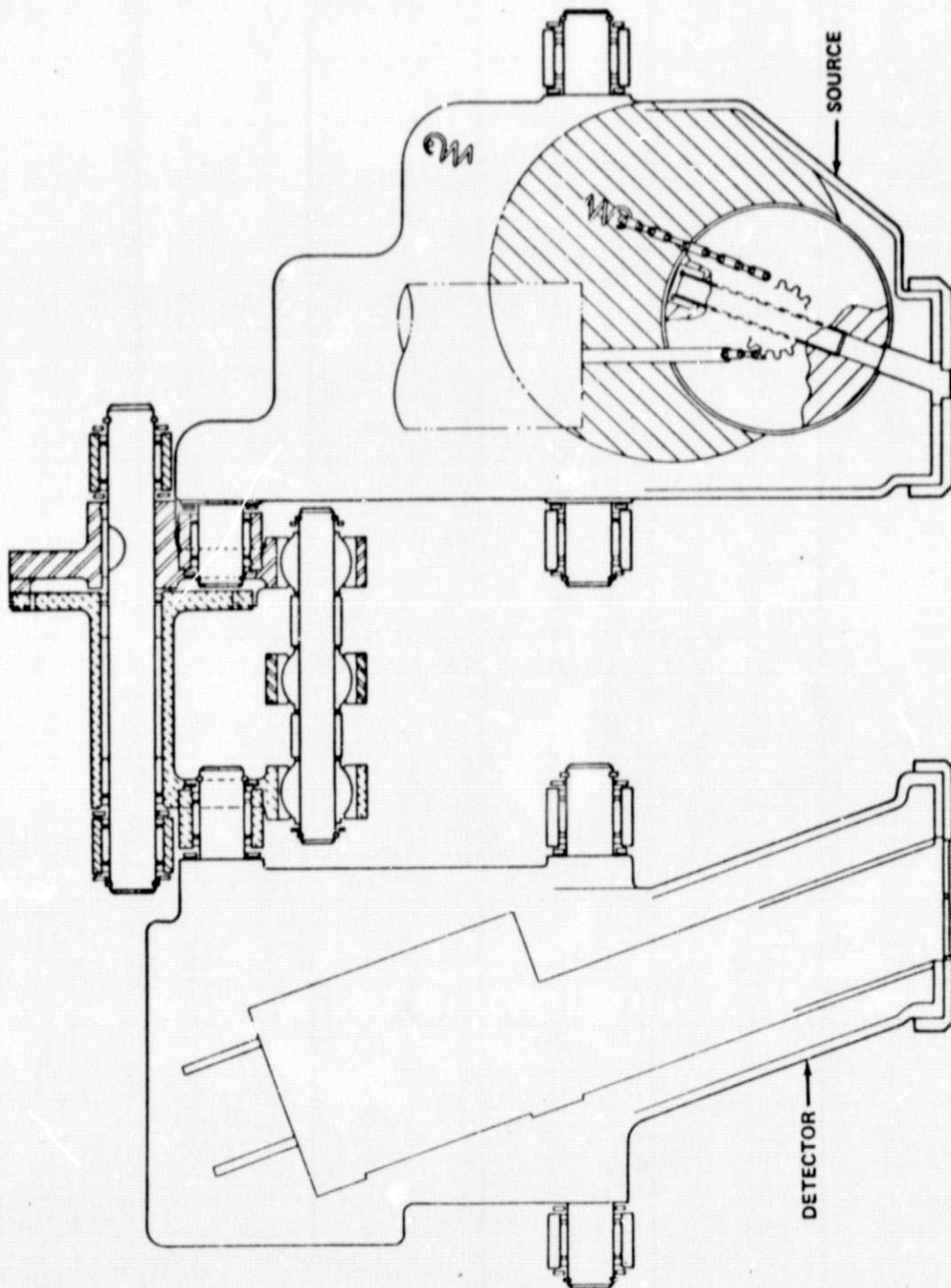


Figure 3.1. (Continued)

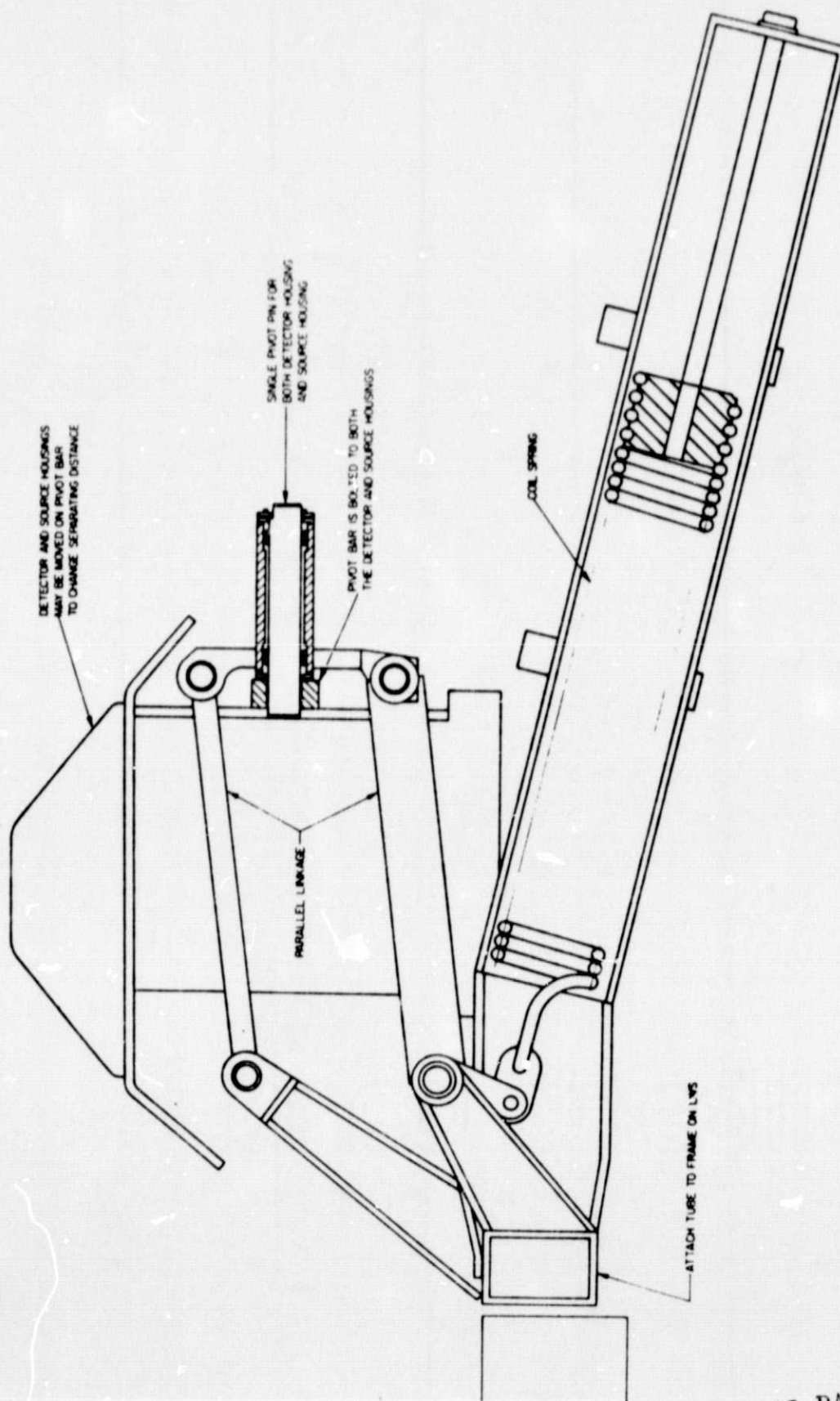


Figure 3.2. Non-Independent Suspension System with Coil Springs

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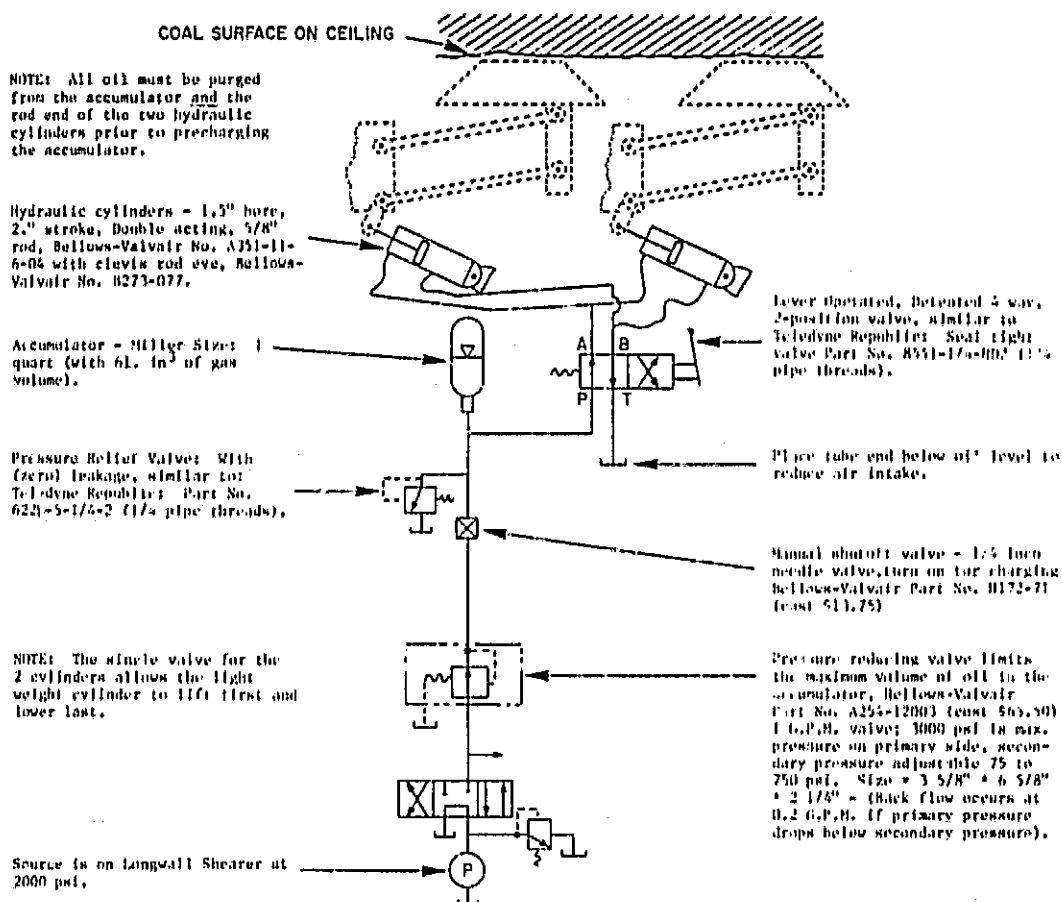


Figure 3.3. Independent Suspension System with Hydropneumatic Springs-Hydraulic Circuit

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the coal surface per Figure 3.3. The volume of air in the accumulator is several times as large as the oil volume to prevent excessive changes in oil pressure during operation. Control valves are used to direct oil flow to different ends of the double acting hydraulic cylinders. The relief valve is shown to prevent damage to the system. The manual shutoff valve allows the accumulator to be refilled. The pressure reducing valve provides oil to the accumulator at the predetermined fill pressure. This fill pressure is selected to provide adequate dynamic response of the CID over its total range of travel.

Since the hydropneumatic spring is a closed volume system, the valves within the active circuit must have zero leakage. If the 4-way valve and the relief valve are difficult to obtain with zero leakage, the 4-way valve may be replaced by manual shutoff valves.

The charging sequence for the accumulator (when sensing depth of coal on roof) is as follows:

- 3.1 Close the manual shutoff valve between accumulator and oil supply.
- 3.2 Shift the 4-way valve to allow both hydraulic cylinders to extend fully.
- 3.3 Shift the 4-way valve to retract the cylinders. This should allow the accumulator to force its remaining oil into the cylinders.
- 3.4 Repeat 3.2 (Accumulator should be void of oil now.)
- 3.5 Pressurize the accumulator to a gas precharge pressure of P2.
(The exact value of P2 is to be established by experiment; however, a theoretical analysis indicates that $P2 = 250$ psia is a reasonable initial estimate. If the system response at the top of the stroke is too slow, this value should be increased.)

- 3.6 Adjust the pressure reducing valve for the oil supply pressure to the value P_1 . (The value of P_1 is a function of P_2 and the volume of gas in the accumulator per equation 4.8. The value of P_1 associated with $P_2 = 250$ psia is: $P_1 = 277$ psig per Chapter 4.)
- 3.7 Open the manual shutoff valve between the accumulator and the oil supply.
- 3.8 After the accumulator oil reaches pressure P_1 , turn off the manual shutoff valve to the oil supply.
- 3.9 Then move the 4-way valve lever to the position where the cylinders retract.
- 3.10 If this procedure is carried out correctly, the cylinders should fully retract at this time and the cylinder pressures should be slightly larger than P_2 .

The pressure drop in the system due to pipe friction and hydraulic cylinder drag will have an adverse effect on the dynamic performance. The static breakaway force for the 1.5 inch diameter cylinder is 15 psi per Bellows-Valvair Corporation. These cylinders are to be procured with Viton or Teflon seals to minimize friction. The hydraulic tube is 0.5 inch diameter to minimize the pressure drop.

Independent parallel 4-bar linkages support the source housing and the detector housing to maintain their vertical orientations per Figure 1.2. (These linkages are defined on layouts 011 and 012.) In order to obtain adjustable separation distances between the source and detector from 10.5 to 22.5 inches, the detector was placed 51 degrees (Figure 1.2) behind the source. This moves the center of the gamma ray path to 54.5 inches behind the shearing drum centerline for the 22.5 separation distance. This distance may be reduced by changing the 51 degree angle and/or relocating

the 4-bar linkages if the requirement on separation adjustment is modified.

The largest lower link of the independent 4-bar linkages serves as the driving link. This driving link is designed to withstand torsional loading on the housing while the other links are uniaxial force members. The joints of the links are sealed, grease packed, needle bearings mounted on heat treated shafts (Rockwell 58C) to minimize distortion due to wear and to minimize friction.

A shear pin is provided per Layout 013 to allow the entire CID to fold down when an excessive vertical force is applied. The CID is illustrated in the normal and folded down positions in Figure 1.2 (Layout 019). The shearing mode of pin failure is assured by holding the clearance between shear surfaces to $.010 \pm .010$ inches per Layout 013.

The accumulator oil inlet is a swivel fitting which is mounted at the CID "fold down" pivot per Layout 014.

Some plumbing recommendations for the pressurized side of the cylinders are shown on Layouts 014 and 015. The hydraulic tube is 37 degree flared seamless tube. However, provisions for attaching the valves and for flexibly connecting the valves to sump are to be determined during assembly. Hydraulic hoses and electrical wiring are to be protected as indicated on Layout 014.

The nucleonic source, which is roughly .375 inches diameter by .625 inches long, is located in the side of a 2.5 inch diameter lead cylinder per Figure 3.4 (Layout 017). This lead cylinder is free to rotate inside of a lead lump of approximately 5 inches diameter. In the inactive position the source is moved to the center of the lead lump to provide roughly 2.5 inches of lead shielding. However, in the active position the cylinder is rotated 180 degrees to move the source under a collimation hole thru the lead lump. (This collimation hole is sealed with a polyurethane diaphragm.)

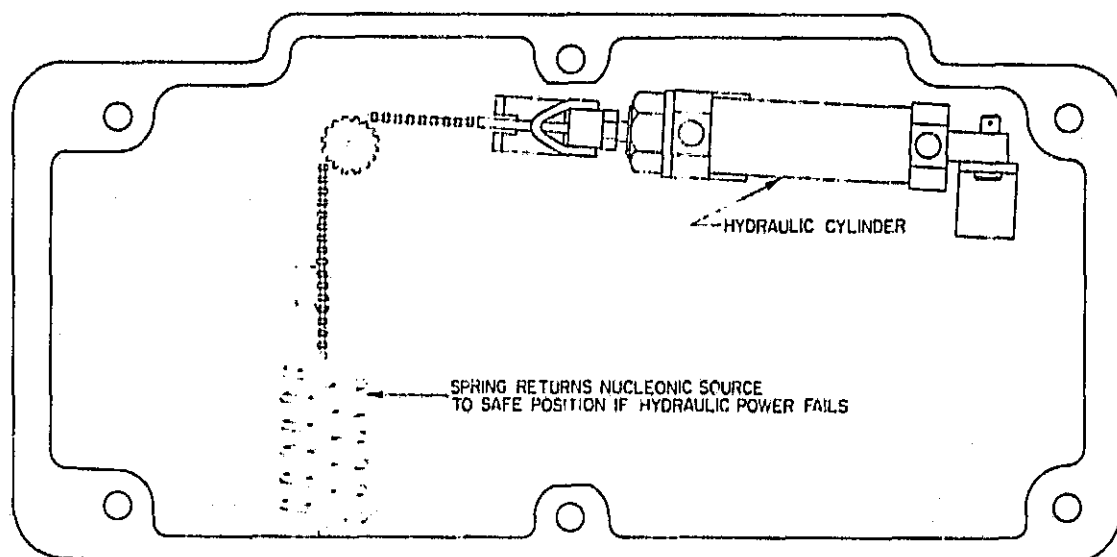
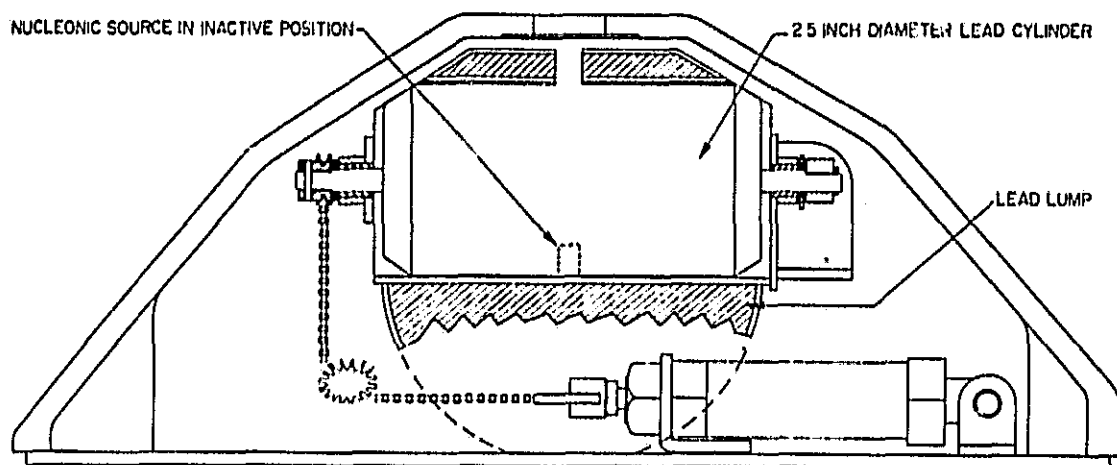


Figure 3.4. Proposal for Actuation of Nucleonic Source by a Hydraulic Slave Cylinder

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Several different configurations for activating and automatically storing the nucleonic source were developed during this study. An activating arrangement using a slave hydraulic cylinder is illustrated in Figure 3.4 (Layout 009). A star wheel plus mutilated gear arrangement (Layout BJ-MB) for actuating the source was constructed. (The star wheel and mutilated gear concepts are discussed in references 2, 3, 4 and 5.) The accepted actuation configuration (see Figure 3.5 and Layout 017) is the spatial 4-bar mechanism which will be described in the following paragraph.

The nucleonic source is automatically rotated 180 degrees from its inactive (i.e., shielded) position into its active position as the source housing moves up against the coal surface and begins to travel forward. The source rotation is initiated by a lever on the side of the source housing which is forced to rotate as the housing moves into contact with the coal. The lever rotation tends to wind up a torsion spring which drives the spatial 4-bar linkage which rotates a pair of gears. The driven gear is fixed to the lead cylinder containing the source and rotates 180 degrees. The lever arm will continually oscillate as it slides along the undulating coal surface under the force of an extension spring. Meanwhile, the torsion spring acts as an elastic link in the spatial 4-bar to fix the nucleonic source at its active position as long as the housing contacts the coal surface. However, when the housing is removed from the coal surface the extension spring will rotate the lever to its vertical position and pull the nucleonic source back into the inactive position.

The position of the nucleonic source may be determined by observing the lever position or by observing two signal lights on the control panel of the LWS. These lights are energized by separate proximity switches which are located inside the source housing as illustrated in Figure 3.6 (Layout 017). One light is energized when the source is in the active position

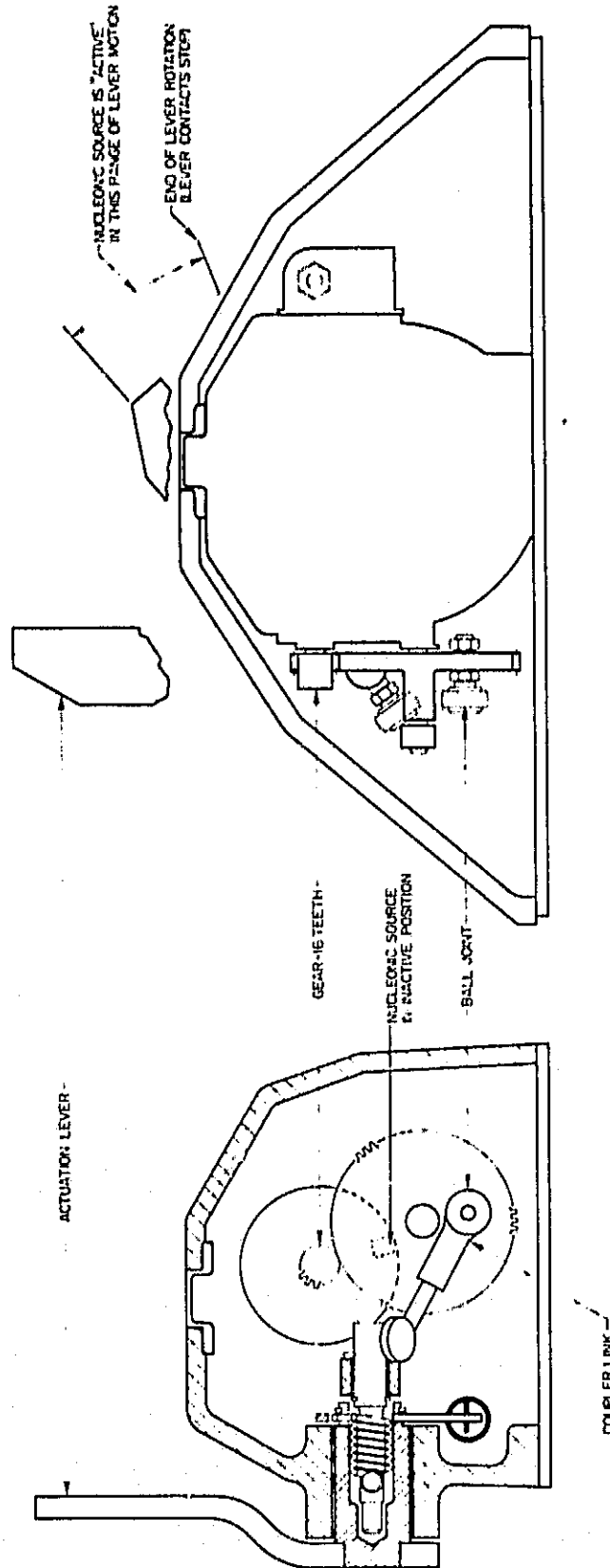


Figure 3.5. Nucleonic Source, Housing and Spatial 4-Bar Linkage, Actuation Mechanism

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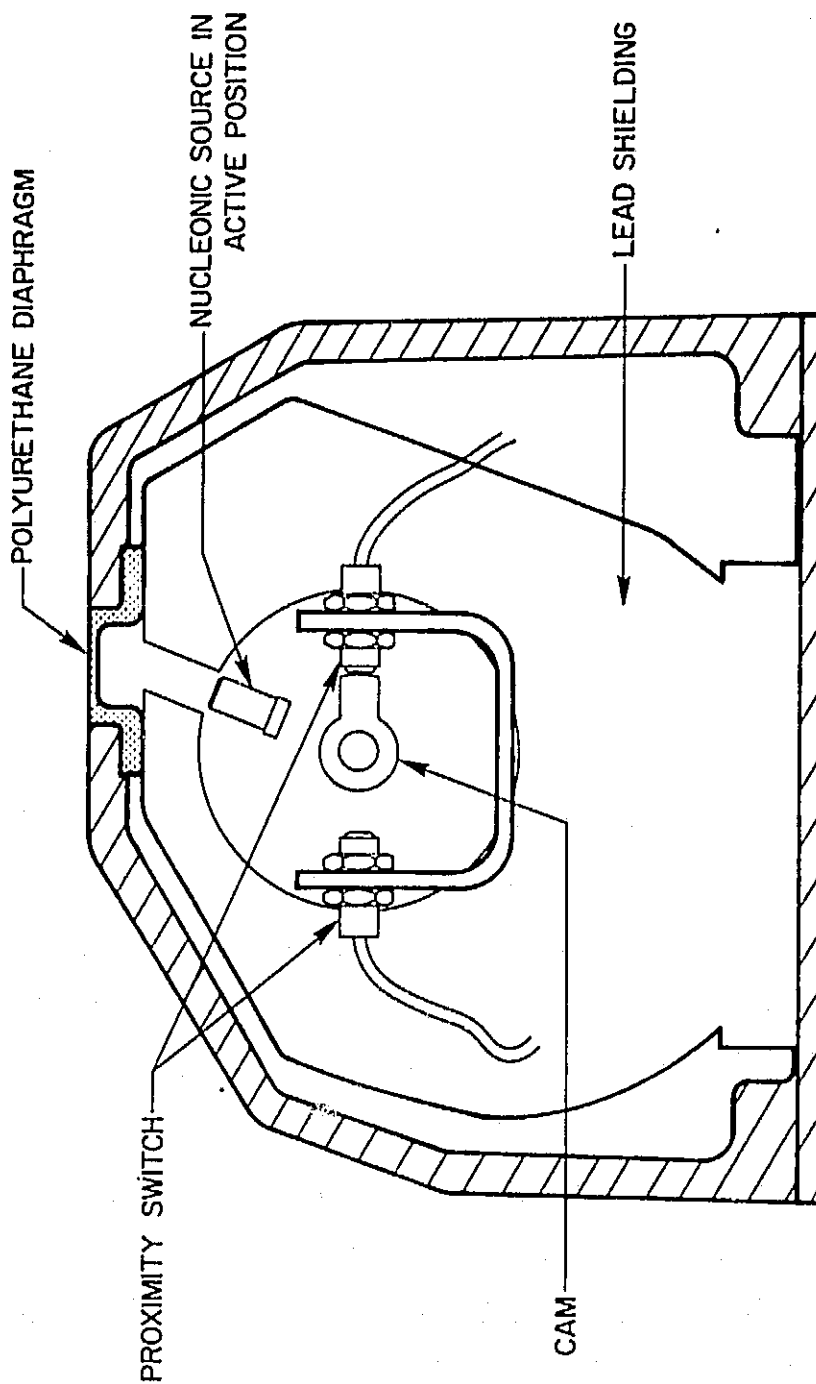


Figure 3.6. Proximity Switches Indicate Position of Nucleonic Source

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and the other light is energized when the source is in the inactive position. The positions of the proximity switches are adjustable relative to the actuating cam. Care should be taken to adjust the "active" light to energize when the source is aligned with the collimation opening.

The spatial 4-bar coupler link is adjustable to allow the lever to be positioned at 48.5 degrees from the vertical when the source is aligned with the collimation opening. A bolt is to act as a one-way stop against the segment gear when the source is aligned with the collimation opening. This bolt may require some positional adjustment. The pinion set screw is to be tightened while the bolt is in contact with the gear segment and the source is at the opening. The source will rotate approximately 180 degrees into the inactive position when the lever rotates 48.5 degrees to the vertical position. The plate which covers the front of the bottom of the source housing may be removed to assemble the lever.

The gears in the source housing are to be lubricated with "open gear lubricant" which is produced by Boston Gear Company. All of the bushings are self lubricated oil impregnated bronze.

The housings for the source and detector are to be SAE 1045 steel to minimize wear at the contact surfaces.

The nucleonic detector which measures the intensity of the back-scattered gamma rays is the Scintillation Detector 549-155, Drawing Number 549-0551, by EMR Photoelectric, Division of Western Instruments Inc. This detector is mounted inside the detector housing per Figure 3.7 (Layouts 020 and 021). The path of the gamma rays entering the detector is encircled by a 3 inch diameter lead cylinder to attenuate spurious signals which are not traveling along the 20 degree entrance path. This entrance path is open to the coal surface except for a .125 inch thick polyurethane diaphragm which seals the opening.

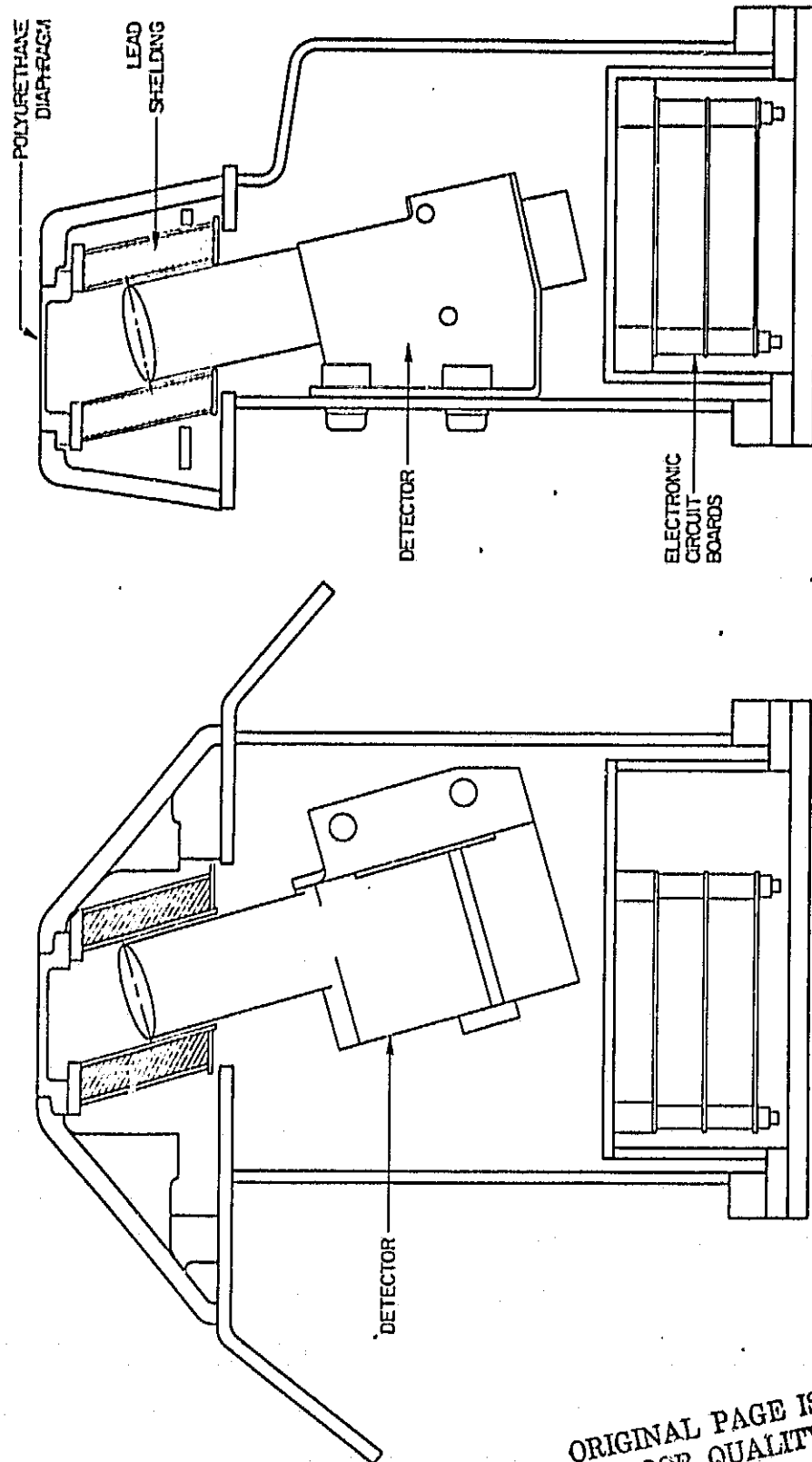


Figure 3.7. Scintillation Detector in Housing

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A signal preprocessing circuit is located adjacent to the Scintillation Detector. This circuit is located in a small steel box inside the housing. This circuit box was originally designed to be explosion proof per BOM Schedule 2G. However, the requirement for an explosion proof box was subsequently removed for the prototype, which is not to be used inside a mine, and the box was then modified to use a standard connector leading to the Scintillation Detector. The cable leading into the box from the LWS control panel was not redesigned. This cable has a mechanical interlock which requires the cable to be disconnected prior to removal of the cover on the "explosion proof" box. When this cable is disconnected, one of its 26 open circuits is to be used to cut off all power to the "explosion proof" box.

CHAPTER 4
DYNAMIC RESPONSE OF HYDROPNEUMATIC
SUSPENSION SYSTEM

The ability of the source and detector housings to maintain contact with the rough roof surface may be estimated via a mathematical model of the dynamical system. The actual system has two degrees of freedom; however, the math model will be formulated for a single degree of freedom system by assuming that the two housings move in unison. This simple math model will provide some design direction. Thus the dynamical system consists of the distributed masses of the housings and linkages, the accumulator, the two hydraulic cylinders, the hydraulic fluid and the linkage per Figure 4.1. The math model will be based on the change in kinetic and potential energies and the friction loss.

The kinetic energy, KE, of this system is

$$KE = .5[I_2(d\theta/dt)^2 + I_3(d\theta/dt)^2 + (W_4/G)(V_{CG4})^2 + (W_{ROD}/G)(R * \cos(\theta))^2(d\theta/dt)^2] \quad 4.1$$

However, V_{CG4} , the velocity of the center of gravity of the pair of housings, is a function of $d\theta/dt$, the angular velocity of link 2.

$$V_{CG4} = L * d\theta/dt \quad 4.2$$

This system may be reduced to the equivalent dynamical system of Figure 4.2. The kinetic energy of the equivalent system is

$$KE = .5 * I_{EQ}[d\theta/dt]^2 \quad 4.3$$

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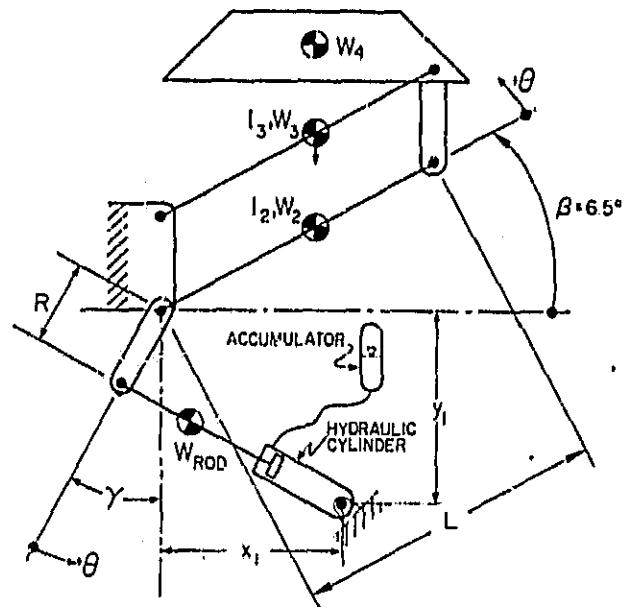


Figure 4.1. Hydropneumatic Suspension System for CID

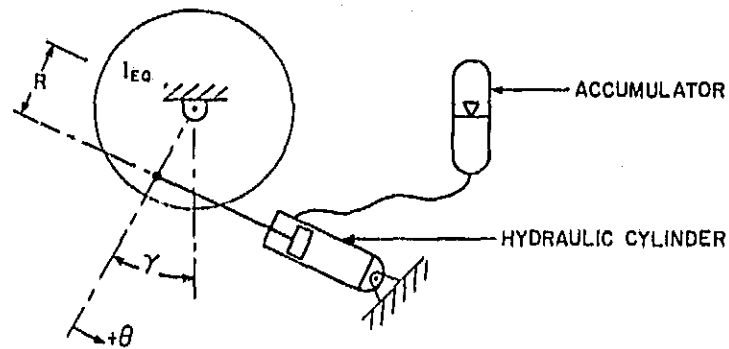


Figure 4.2. System with Equivalent Inertia

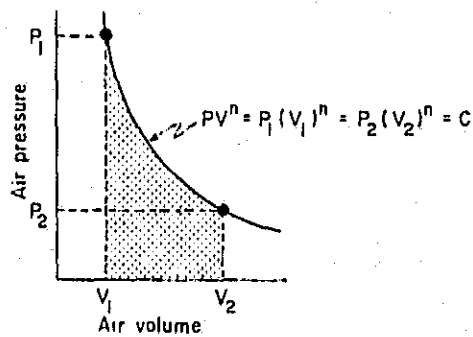


Figure 4.3. Pressure vs. Volume for Gas Bladder in Accumulator

However, if the equivalent system is to behave like the original system, the kinetic energy of both systems must be identical. Hence, Equation 4.1 may be set equal to Equation 4.3 and the result combined with Equation 4.2 to produce the following equation.

$$I_{EQ} = I_2 + I_3 + (W_4/G)(L)^2 + (W_{ROD}/G)[R * \cos(\theta)]^2 \quad 4.5$$

The above nonlinear equation furnishes the mathematical definition of the "equivalent inertia", I_{EQ} , of the equivalent system.

The potential energy of the original system consists of the energy stored in the compressed gas of the accumulator plus the energy due to position of the weights in the gravity field. The change in potential energy of the accumulator as the gas volume expands from V_1 to V_2 (per Figure 4.3) is

$$PE_{a2} - PE_{a1} = \int_{V_1}^{V_2} P dV \quad 4.6$$

However, gas pressure is a function of gas volume.

$$C = PV^n = P_1[V_1]^n = P_2[V_2]^n \quad 4.7$$

(The value of n is 1.4 for the process of adiabatic compression of air.)

Hence,

$$\frac{V_2}{V_1} = \left(\frac{P_2}{P_1}\right)^{-1/n} \quad 4.8$$

Integration of Equation 4.6 plus substitution of 4.7 and 4.8 gives the following equation.

$$(PE_{a2} - PE_{a1}) = [(P_1 * V_1)/(1-n)][(P_2/P_1)^{([n-1]/n)} - 1] \quad 4.9$$

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The potential energy due to weight position is

$$PE_w = L * [\sin (\theta + \beta)] * (W_2/2 + W_3/2 + W_4) \quad . \quad 4.10$$

The fluid friction is estimated to produce a 14 psi pressure drop at a 3.93 in³/min flow rate. This estimate is based on the use of 0.5 inch tube with hose and fittings as shown on Layout 015. References 10 and 11 describe the method of calculation. Tellef 33 oil [7] was used. In the math model, the friction pressure drop, ΔP , is assumed to be directly proportional to the flow rate, $\Delta V/\Delta t$.

$$\Delta P = (14/3.93) * (\Delta V/\Delta t) \quad 4.11$$

where, ΔV = change in volume of oil in accumulator, in³.

Δt = time required for volume change, ΔV , sec.

but power loss, $\Delta E/\Delta t$, is a function of pressure drop and flow rate.

$$\Delta E/\Delta t = \Delta P * (\Delta V/\Delta t) \quad 4.12$$

Hence, the energy loss, ΔE , due to an accumulator volume change, ΔV , is

$$\Delta E = (14/3.93) (\Delta V) (\Delta V/\Delta t) \quad 4.13$$

where, ΔE = energy loss due to friction during time Δt , lb-in.

If the system energy at time t_1 is compared to the energy at time t_2 , where

$$t_2 = t_1 + \Delta t \quad , \quad 4.14$$

the following expression may be obtained

$$PE(t_2) - PE(t_1) + KE(t_2) - KE(t_1) + \Delta E = 0 \quad . \quad 4.15$$

Let Δt be defined as the time required for a quantity of oil ΔV to flow out of the accumulator. The numerical size of ΔV is the same as the change

in accumulator gas volume. Hence,

$$\Delta V = V_2 - V_1 \quad . \quad 4.16$$

Define the speed at time t_1 by,

$$\text{OMEGA} = \frac{d\theta(t_1)}{dt}$$

Therefore, Equation 4.15 may be expanded as follows by using Equations 4.3, 4.9, 4.10, 4.13 and 4.16.

$$\begin{aligned} L * [W_2/2. + W_3/2. + W_4][\sin[\theta(t_2) + \beta] - \sin[\theta(t_1) + \beta]] \\ + [P_1 * V_1/(1-n)][(P_2/P_1)^{(n-1)/n} - 1] \\ + .5 * [I_{EQ}(t_2)][d\theta(t_2)/dt]^2 - .5 * [I_{EQ}(t_1)][\text{OMEGA}]^2 \\ + 3.56[V_2 - V_1](\Delta V/\Delta t) = 0 \quad . \end{aligned} \quad 4.17$$

The friction loss term in the above equation will have small influence on the results since it is a lower order term in t and since friction loss is low. In order to simplify the solution, the values for Δt in the integration will be held low so the value of $\Delta V/\Delta t$ may be estimated based on omega and the piston size.

$$\begin{aligned} DQTOT = \Delta V/\Delta t = 2 * \text{OMEGA} * R * \cos[\theta(t_1) - \text{GAMMA}] * 3.14 * \\ [(Piston \text{ Dia.})^2 - (Rod \text{ Dia.})^2]/4 \quad . \end{aligned} \quad 4.18$$

The previous two equations may be solved for the total time, t , required for an angular displacement, θ , to occur.

$$t = \Delta\theta \sum_{i=1}^N (1/z)^{.5} \quad 4.19$$

$$\theta = \sum_{i=1}^N \Delta\theta \quad 4.20$$

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where,

$\Delta\theta$ = An incremental angle for numerical integration

$$z = A - AA - AAA - AAAA$$

$$A = (I_{EQ}(t_1)/I_{EQ}(t_2)) (d\theta(t_1)/dt)^2$$

$$AA = (2/I_{EQ}(t_2))(P_1 * V_1/(1-n))[(P_2/P_1)^{([n-1]/n)} - 1]$$

$$AAA = (2/I_{EQ}(t_2))[L[W_2/2 + W_3/2 + W_4][\sin[\theta(t_2) + \beta] - \sin[\theta(t_1) + \beta]]$$

$$AAAA = (2/I_{EQ}(t_2))[3.56(V_2 - V_1)(DQTOT)].$$

The above equation which expresses response time, t , as a function of displacement, θ , was used to evaluate the response speed of this system for different precharge pressures as indicated in Figure 4.4. These response values are based on an initial speed, $d\theta/dt$, equal to zero.

The nonlinear nature of the hydropneumatic spring suspension system prompted an investigation into the influence of the angle gamma on the required precharge pressure per Figure 4.5. Gamma is to be 30 degrees in order to minimize the required pressure.

The slope of the front of the housing contact surface plus the magnitude of the forward speed of the system influence the amount of overshoot as the CID travels under a bump. The rebound height of the sensor after bouncing from the surface depends on the coefficient of restitution for the striking materials. (This type of analysis for the CID with helical coil springs for suspension is shown in Appendix B.)

The oil pressure P_1 (see Figure 4.3) which is required to properly fill the accumulator may be evaluated by Equation 4.8. Let $V_2 = 61 \text{ in}^3$, the empty accumulator bladder volume. Let P_2 be the minimum pressure required to drive the CID. For this example, the value of P_2 is taken as 250 psia which is the minimum value. Let V' be the volume of oil required to fill the two cylinders.

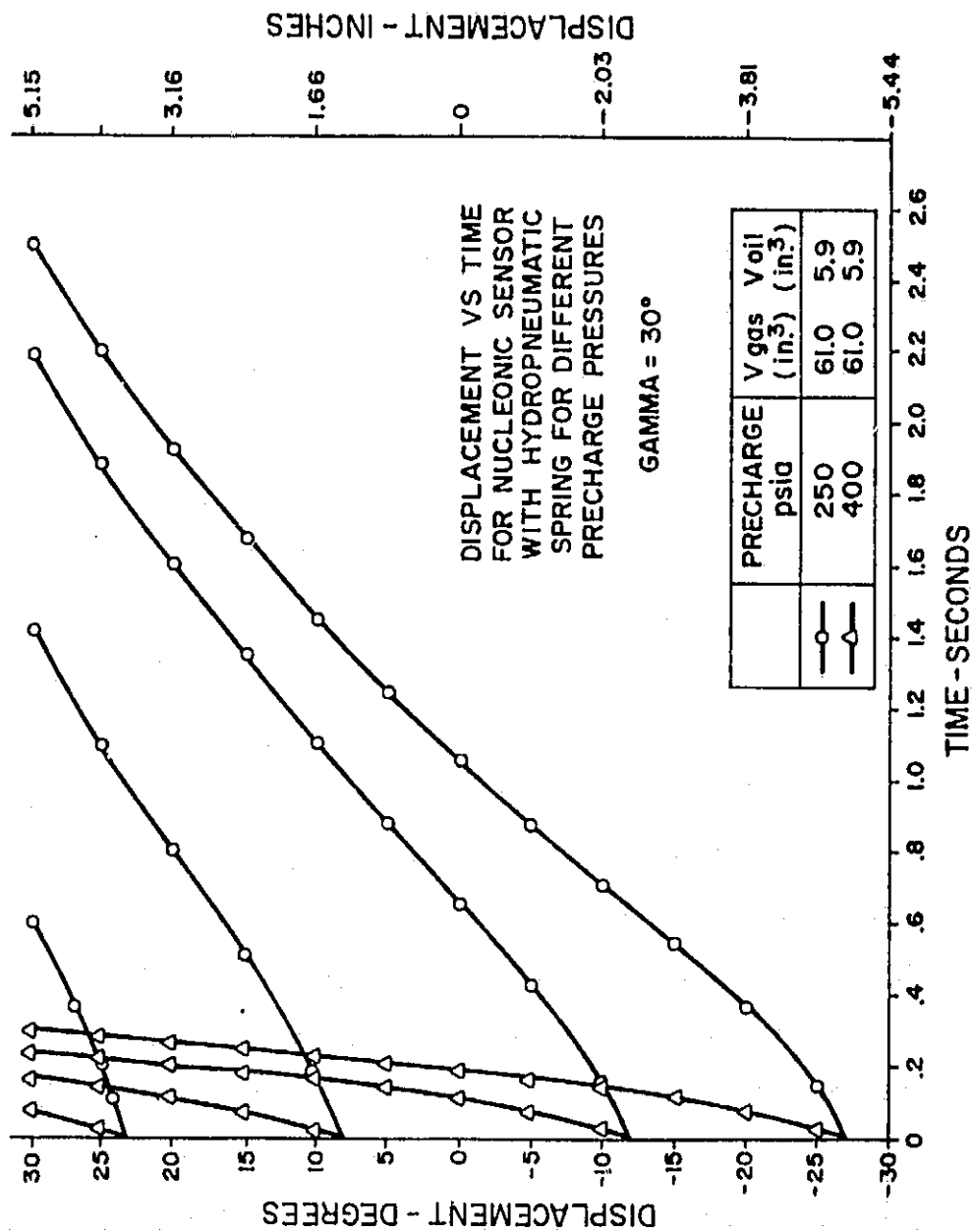


Figure 4.4. Dynamic Response of CID with Hydrodynamic Suspension

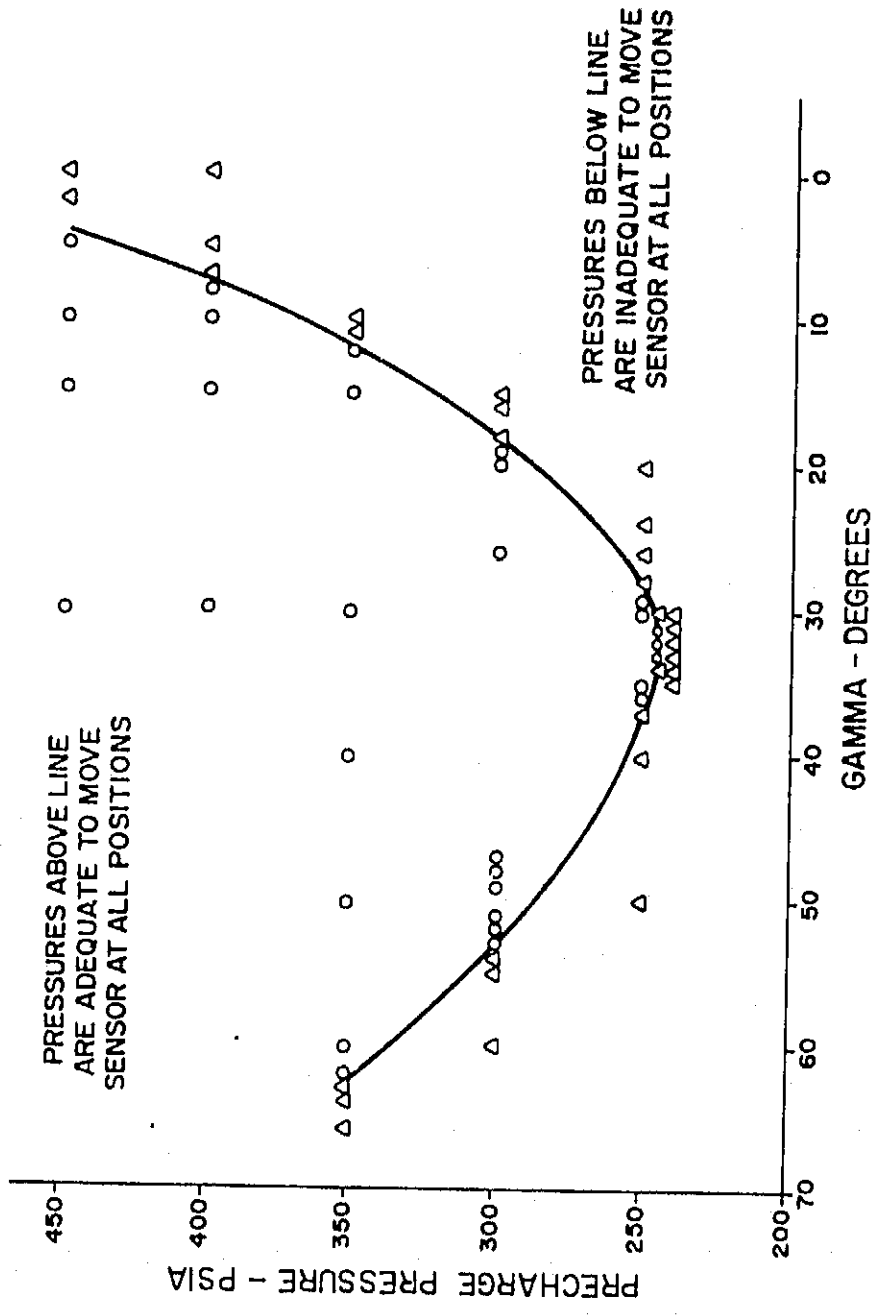


Figure 4.5. Affect of Gamma (γ) on Precharge Pressure Requirements

$$V' = 2\pi[(\text{Piston Dia.})^2 - (\text{Rod Dia.})^2] * \text{Stroke}/4 = 5.84 \text{ in}^3 \quad 4.21$$

Assume the gas stored at pressure P_1 has a volume:

$$V_1 = V_2 - (110\%)V' = 54.6 \quad 4.22$$

(The 10% excess oil is added to make up for leakage, etc.) If the value of P_2 is assumed to be 250 psia per Figure 4.5, then

$$P_1 = P_2 \left(\frac{V_2}{V_1} \right)^n = 250 \left(\frac{61}{54.6} \right)^{1.4} .$$

Therefore, the pump relief valve setting should be

$$P_1 = 292 \text{ psia} = 277 \text{ psig} ,$$

if these values give acceptable dynamical response per Equations 4.19 and 4.20.

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CHAPTER 5

CONSIDERATIONS FOR OPERATION OF CID ON CEILING AND FLOOR

In general the CID is designed for operation on the ceiling of the mine where the hydraulic cylinders must support the weight of the CID and provide adequate acceleration forces. If the CID is to be operated on the floor of the mine, the weight force will add to the cylinder forces if the valve positions are unchanged. Thus it may be desirable to modify the hydraulic pressure setting and/or the valve positions to reduce the contact forces when operating on the floor.

The loose coal on the floor presents another problem. A typical view of this loose coal is shown on Figure 5.1. The loose coal should be scraped away from the path of the CID by the LWS to allow the CID to contact the floor directly. Otherwise the variable depth of loose coal will introduce errors in measurement. The loose material could also pile up in front of the CID as it slides along the floor.

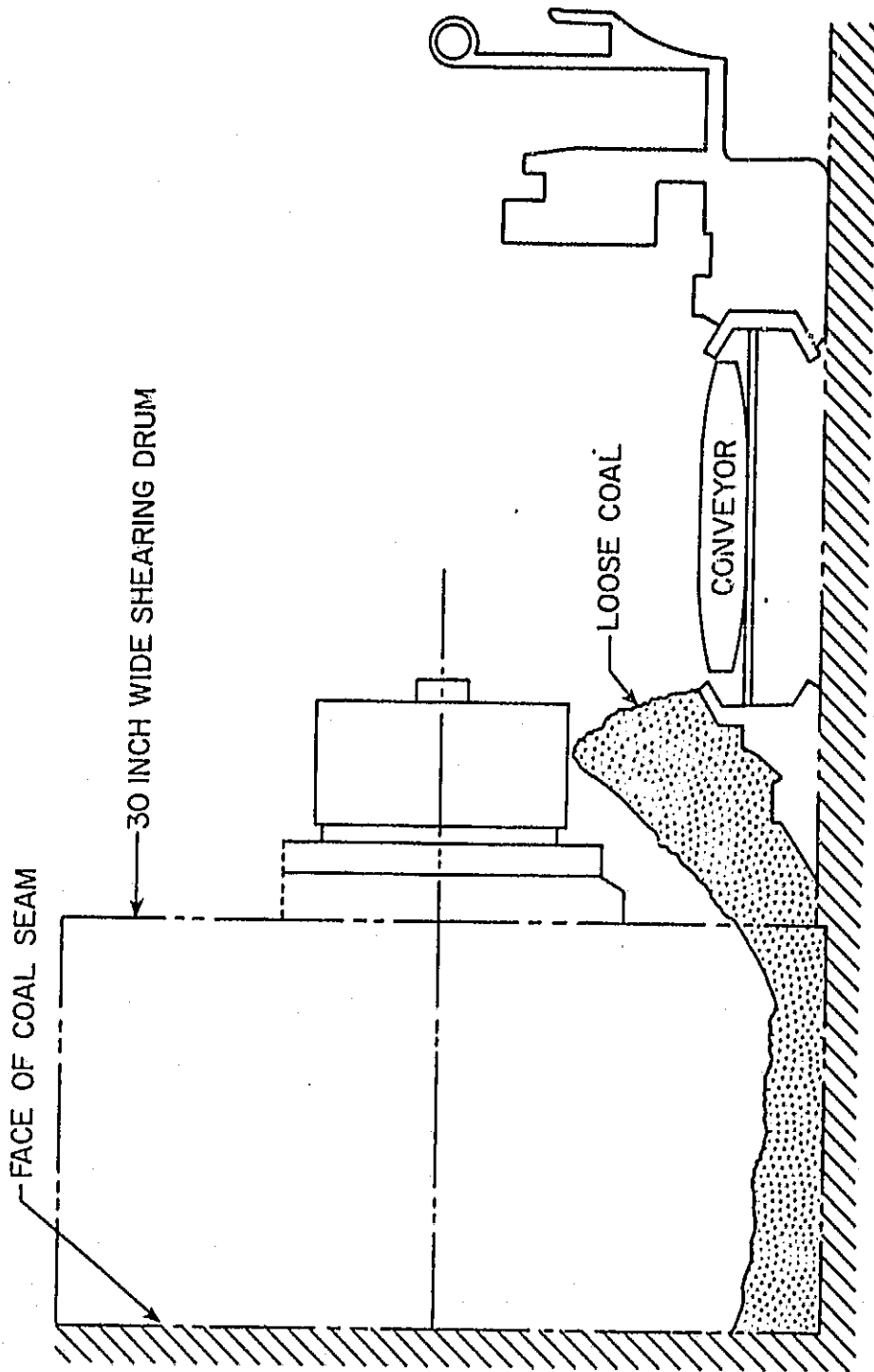


Figure 5.1. Coal on Floor Behind Shearing Drum

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CHAPTER 6

RECOMMENDATIONS AND SUMMARY

Recommendations

- 6.1 Reduce the range of separation distance, if possible, and then modify the CID to reduce its rearward overhang and size.
- 6.2 Experimentally determine the response time of the CID as it moves over a bump on the roof to verify the theoretical response analysis and to determine the desired precharge pressure.
- 6.3 Test the shear pin in static and fatigue loading.
- 6.4 Add a spring, chain or bumper to cushion the fall of the CID when the pin shears.
- 6.5 Experimentally investigate the ability of the CID to travel in reverse (while at its upper position) without "locking up" against the roof.
- 6.6 Measure breakaway force and drag of the hydraulic cylinders.
- 6.7 If electronic circuits are intrinsically safe, reduce size of detector housing by elimination of explosion proof box concepts.
- 6.8 Check hydraulic system for leaks in valves which will bleed the closed system.
- 6.9 If zero leakage 2-position valves and relief valves are not readily available, modify hydraulic system. Note: It is estimated that each of the two Teledyne Republic valves in Figure 3.3 will leak at about one drop per minute (.22 cu.in./hr.). This leakage should be measured to determine the percent overfill needed by the accumulator to provide an acceptable life span for an accumulator charge.

6.10 Determine if any adverse effect is caused by lack of "make up" oil on the head end of the cylinder when the CID is on the ceiling.

Summary

The design and response of a Nucleonic Coal Interface Detector for determining the depth of coal on the ceiling or floor of a mine is presented. This instrument consists of a nucleonic source which emits gamma rays and a Scintillation Detector. This instrument is different from the existing Nucleonic CID as it has two relatively small contact surfaces and the nucleonic source and the Scintillation Detector are mounted on separate independent suspensions. These differences should reduce measurement errors caused by the rough coal surface. This instrument also has an adjustable distance between the nucleonic source and the detector to facilitate measurement of different coal thicknesses. The suspension system uses hydropneumatic springs which allow modification of the response time by changing the precharge pressure of an accumulator. The nucleonic source is automatically rotated inside a lead shield when the instrument is not in contact with the coal surface.

Kim Handy's forthcoming M.S. thesis will cover the material of this final report plus some related topics.

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APPENDIX A

COMPUTER LISTING FOR RESPONSE ANALYSIS

```

3* C THIS PROGRAM ANALYZES THE RESPONSE TIME OF THE CID WITH A HYDRAULIC
4* PNEUMATIC SPRING SUSPENSION
5* PROGRAM WILL CONSIDER THE ENERGY LOSS IN THE TUNING, THIS 38
6* ENERGY LOSS IS ASSUMED TO BE PROPORTIONAL TO FLOW RATE
7* DTORAD IS DEGREES TO RADIANS
8* RADTOD IS RADIANS TO DEGREES
9* APIST= AREA OF ROD END OF PISTON \ IN**2
10* GAMMA IS THE ANGLE BETWEEN THE LEVER ARM AT THE CYLINDER AND VERTICAL. DEG
11* BETA IS THE ANGLE FROM PARALLEL LINK TO HORIZONTAL WHEN THET1 IS ZERO
12* I2 IS THE INERTIA OF LOWER LINKS OF PARALLEL BARS - LR IN SEC**2
13* I3 IS THE INERTIA OF UPPER LINKS OF PARALLEL BARS - LR IN SEC**2
14* L IS THE LENGTH OF PARALLEL BARS - IN
15* OMEGA IS THE TIME RATE OF CHANGE OF THETA1 - RADIANS/SEC
16* W2 IS THE WEIGHT OF LOWER PARALLEL LINKS - LR
17* W3 IS THE WEIGHT OF UPPER PARALLEL LINKS - LR
18* W4 IS THE WEIGHT OF BOTH SENSOR HEADS - LB
19* WROD IS THE WEIGHT OF THE PISTON ROD - LR
20* PPRE IS THE PRECHARGE PRESSURE OF THE ACCUMULATOR - PSIA
21* VPRE IS THE VOLUME OF GAS AT THE PRECHARGE PRESSURE - IN**3
22* VMIN = MINIMUM VOLUME OF GAS IN ACCUMULATOR I.E. VPRE LESS VOLUME
23* REQUIRED TO FILL TWO CYLINDERS TIMES A SAFETY FACTOR.
24* REAL IEQ1,IEQ2
25* REAL L,I2,I3
26* DTORAD=3.14159265/180.
27* RADTOD=1./DTORAD
28* C*****+*****
29* GAMMA = 30.
30* I3=1.04
31* I2=2.7
32* R=2.
33* L=10.625
34* I2=12.7
35* W2=4.1
36* W4=136.
37* G=386.
38* VPRE=61.
39* PPRE=350.
40* APIST=(3.14159265/4.)*(1.5**2.-.625**2.) *2.
41* VMIN=61.-5.84

42* ALPHA=-27.
43* THEMAY=30.0*DTORAD
44* BETA=6.5*DTORAD
45* DTTHETA=1.0*DTORAD
46* GAMMA=GAMMA*DTORAD
47* 21 CONTINUE
48* IF(ALPHA.GT.30)GO TO 70
49* OMEGA=0.0
50* WRITE(6,61)ALPHA
51* 61 FOR AT(11,50X,'ALPHA=',F5.1,/,/,24X,'THETA',11X,'TIME',13X,'DT',1
52* 03X,'IEQ1',12X,'OMEGA',12X,'VERTICLE DISPLACEMENT',/)
53* THETA=ALPHA
54* TIME=0.0
55* WRITE(6,60) THETA,TIME
56* 30 CONTINUE
57* THETA=THETA*DTORAD
58* THET2=THETA*DTTHETA
59* IF(THETA.GT.THEMAY)GO TO 50
60* X1=7.65+2.*SIN(GAMMA-THETA)
61* Y1=6.55-2.*COS(GAMMA-THETA)
62* S1=SQRT(X1**2.+Y1**2.)
63* X2=7.65+2.*SIN(GAMMA-THET2)
64* Y2=6.55-2.*COS(GAMMA-THET2)
65* S2=SQRT(X2**2.+Y2**2.)
66* V1=VMIN-APIST*(S1-10.875)
67* V2=VMIN-APIST*(S2-10.875)
68* WROD=7.
69* IEQ1=I2+I3+(W4/G)*L**2. + ABS((WROD/G)*R**2.*(COS(THETA))**2.)
70* IEQ2=I2+I3+(W4/G)*L**2. + ABS((WROD/G)*R**2.*(COS(THET2))**2.)
71* DELP1=(W2/2.*W3/2.+W4)*(SIN(THET2+BETA)-SIN(THETA+BETA))
72* P1=PPRE*(VPRE/V1)+1.4
73* P2=PPRE*(VPRE/V2)+1.4
74* V=OMEGA*R*COS(THETA-GAMMA)
75* DOTOT=V+2.*3.14159265*(1.5**2.-.625**2.)/4.
76* C DPF = PRESSURE DROP DUE TO FRICTION. IT IS ASSUMED TO BE PROPORTIONAL TO
77* C FLOW RATE. AT 3.93IN**3/SEC THE DROP IS 14PSI
78* DPF=14.*(DOTOT/3.93)
79* A=(IEQ1/IEQ2)*OMEGA**2.
80* AA=(2./IEQ2)*(P1/1.4)+V1*((P2/P1)**(.4/1.4)-1.)
81* AAA=2.*DELP/IEQ2
82* AAAA=2.*DPF*(V2-V1)/IEQ2
83* DT=DTTHETA/SQRT(A-AA-AAAA-AAAA)
84* VERTDLEL=SIN(THETA)
85* THET2=THET2+RADTOD
86* 69 WRITE(6,60)THET2,TIME,DT,IEQ1,OMEGA,VERTDLEL
87* 60 FOR AT(21X,F10.5,6X,F10.5,6X,F10.5,6X,F10.3,6X,F10.3,11X,F10.3)
88* THET2=THET2*DTORAD
89* OMEGA=DTTHETA/DT
90* THETA=THETA*DTTHETA
91* TIME=TIME+DT
92* THETA=THETA+RADTOD
93* GO TO 30
94* 50 ALPHA=ALPHA+5.
95* GO TO 21
96* 70 STOP
97* END

```

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ALPHA=-27.0

VERTICLE DISPLACEMENT
(INCHES)

OMEGA

TEQI

DT

TIME
(SEC)THETA
(DEGREES)

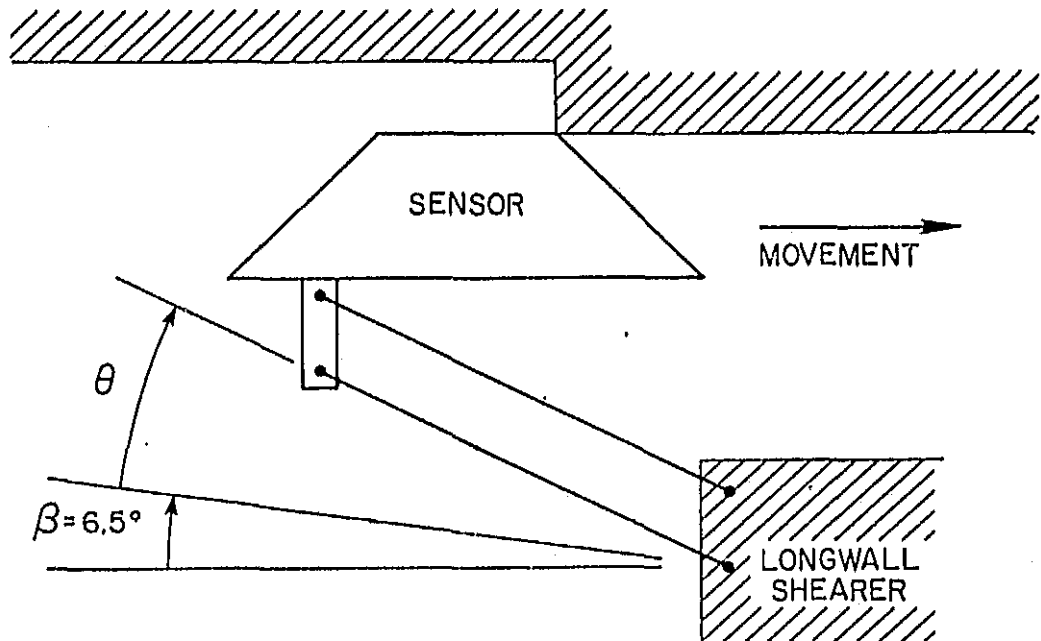
-27.00000	.00000	.02404	43.540	.000	0.824
-26.00000	.00000	.01725	43.540	.000	0.658
-25.00000	.00000	.01425	43.540	.000	0.490
-24.00000	.00000	.01244	43.541	.000	0.322
-23.00000	.00000	.01120	43.541	.000	0.152
-22.00000	.00000	.01029	43.542	.000	0.000
-21.00000	.00000	.00959	43.542	.000	0.980
-20.00000	.00000	.00899	43.542	.000	0.808
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-18.00000	.00000	.00811	43.543	.000	0.459
-17.00000	.00000	.00765	43.543	.000	0.283
-16.00000	.00000	.00720	43.544	.000	0.100
-15.00000	.00000	.00674	43.544	.000	0.929
-14.00000	.00000	.00628	43.544	.000	0.750
-13.00000	.00000	.00583	43.544	.000	0.570
-12.00000	.00000	.00537	43.544	.000	0.390
-11.00000	.00000	.00491	43.545	.000	0.209
-10.00000	.00000	.00445	43.545	.000	0.027
-9.00000	.00000	.00399	43.545	.000	0.845
-8.00000	.00000	.00353	43.545	.000	0.662
-7.00000	.00000	.00307	43.546	.000	0.479
-6.00000	.00000	.00261	43.546	.000	0.295
-5.00000	.00000	.00215	43.546	.000	0.111
-4.00000	.00000	.00169	43.546	.000	0.926
-3.00000	.00000	.00123	43.546	.000	0.741
-2.00000	.00000	.00077	43.546	.000	0.556
-1.00000	.00000	.00031	43.546	.000	0.371
0.00000	.00000	.00000	43.546	.000	0.185
1.00000	.00000	.00000	43.546	.000	0.000
2.00000	.00000	.00000	43.546	.000	0.171
3.00000	.00000	.00000	43.546	.000	0.345
4.00000	.00000	.00000	43.546	.000	0.519
5.00000	.00000	.00000	43.546	.000	0.693
6.00000	.00000	.00000	43.546	.000	0.867
7.00000	.00000	.00000	43.546	.000	1.041
8.00000	.00000	.00000	43.546	.000	1.215
9.00000	.00000	.00000	43.546	.000	1.389
10.00000	.00000	.00000	43.546	.000	1.563
11.00000	.00000	.00000	43.546	.000	1.737
12.00000	.00000	.00000	43.546	.000	1.911
13.00000	.00000	.00000	43.546	.000	2.085
14.00000	.00000	.00000	43.546	.000	2.259
15.00000	.00000	.00000	43.546	.000	2.433
16.00000	.00000	.00000	43.546	.000	2.607
17.00000	.00000	.00000	43.546	.000	2.781
18.00000	.00000	.00000	43.546	.000	2.955
19.00000	.00000	.00000	43.546	.000	3.129
20.00000	.00000	.00000	43.546	.000	3.303
21.00000	.00000	.00000	43.546	.000	3.477
22.00000	.00000	.00000	43.546	.000	3.651
23.00000	.00000	.00000	43.546	.000	3.825
24.00000	.00000	.00000	43.546	.000	4.000
25.00000	.00000	.00000	43.546	.000	4.174
26.00000	.00000	.00000	43.546	.000	4.348
27.00000	.00000	.00000	43.546	.000	4.522
28.00000	.00000	.00000	43.546	.000	4.696
29.00000	.00000	.00000	43.546	.000	4.870
30.00000	.00000	.00000	43.546	.000	5.044
31.00000	.00000	.00000	43.546	.000	5.218
32.00000	.00000	.00000	43.546	.000	5.392
33.00000	.00000	.00000	43.546	.000	5.566
34.00000	.00000	.00000	43.546	.000	5.740
35.00000	.00000	.00000	43.546	.000	5.914
36.00000	.00000	.00000	43.546	.000	6.088
37.00000	.00000	.00000	43.546	.000	6.262
38.00000	.00000	.00000	43.546	.000	6.436
39.00000	.00000	.00000	43.546	.000	6.610
40.00000	.00000	.00000	43.546	.000	6.784
41.00000	.00000	.00000	43.546	.000	6.958
42.00000	.00000	.00000	43.546	.000	7.132
43.00000	.00000	.00000	43.546	.000	7.306
44.00000	.00000	.00000	43.546	.000	7.480
45.00000	.00000	.00000	43.546	.000	7.654
46.00000	.00000	.00000	43.546	.000	7.828
47.00000	.00000	.00000	43.546	.000	8.002
48.00000	.00000	.00000	43.546	.000	8.176
49.00000	.00000	.00000	43.546	.000	8.350
50.00000	.00000	.00000	43.546	.000	8.524
51.00000	.00000	.00000	43.546	.000	8.698
52.00000	.00000	.00000	43.546	.000	8.872
53.00000	.00000	.00000	43.546	.000	9.046
54.00000	.00000	.00000	43.546	.000	9.220
55.00000	.00000	.00000	43.546	.000	9.394
56.00000	.00000	.00000	43.546	.000	9.568
57.00000	.00000	.00000	43.546	.000	9.742
58.00000	.00000	.00000	43.546	.000	9.916
59.00000	.00000	.00000	43.546	.000	10.090
60.00000	.00000	.00000	43.546	.000	10.264
61.00000	.00000	.00000	43.546	.000	10.438
62.00000	.00000	.00000	43.546	.000	10.612
63.00000	.00000	.00000	43.546	.000	10.786
64.00000	.00000	.00000	43.546	.000	10.960
65.00000	.00000	.00000	43.546	.000	11.134
66.00000	.00000	.00000	43.546	.000	11.308
67.00000	.00000	.00000	43.546	.000	11.482
68.00000	.00000	.00000	43.546	.000	11.656
69.00000	.00000	.00000	43.546	.000	11.830
70.00000	.00000	.00000	43.546	.000	12.004
71.00000	.00000	.00000	43.546	.000	12.178
72.00000	.00000	.00000	43.546	.000	12.352
73.00000	.00000	.00000	43.546	.000	12.526
74.00000	.00000	.00000	43.546	.000	12.700
75.00000	.00000	.00000	43.546	.000	12.874
76.00000	.00000	.00000	43.546	.000	13.048
77.00000	.00000	.00000	43.546	.000	13.222
78.00000	.00000	.00000	43.546	.000	13.396
79.00000	.00000	.00000	43.546	.000	13.570
80.00000	.00000	.00000	43.546	.000	13.744
81.00000	.00000	.00000	43.546	.000	13.918
82.00000	.00000	.00000	43.546	.000	14.092
83.00000	.00000	.00000	43.546	.000	14.266
84.00000	.00000	.00000	43.546	.000	14.440
85.00000	.00000	.00000	43.546	.000	14.614
86.00000	.00000	.00000	43.546	.000	14.788
87.00000	.00000	.00000	43.546	.000	14.962
88.00000	.00000	.00000	43.546	.000	15.136
89.00000	.00000	.00000	43.546	.000	15.310
90.00000	.00000	.00000	43.546	.000	15.484
91.00000	.00000	.00000	43.546	.000	15.658
92.00000	.00000	.00000	43.546	.000	15.832
93.00000	.00000	.00000	43.546	.000	16.006
94.00000	.00000	.00000	43.546	.000	16.180
95.00000	.00000	.00000	43.546	.000	16.354
96.00000	.00000	.00000	43.546	.000	16.528
97.00000	.00000	.00000	43.546	.000	16.702
98.00000	.00000	.00000	43.546	.000	16.876
99.00000	.00000	.00000	43.546	.000	17.050
100.00000	.00000	.00000	43.546	.000	17.224

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APPENDIX B
DETECTOR WITH NONINDEPENDENT
SUSPENSION--CONCEPT AND RESPONSE

A CID with nonindependent suspension of the nucleonic source and Scintillation Detector is developed on Layouts 001 thru 009 and is illustrated in Figure 3.2. This design uses helical coil springs to maintain contact between the CID and the coal surface.

The vertical displacement of the suspended mass as it moves under a downward step in the mine roof per Figure B1.1 is shown in Figure B1.2. This response is based on a horizontal velocity of 30 feet per minute.



EQUATIONS FOR SYSTEM:

$$I_{EQ} \ddot{\theta} = T_C$$

$$\theta = \frac{T_C}{2I_{EQ}} t^2 + t \dot{\theta}_{INITIAL} + \theta_{INITIAL}$$

Figure B1.1. Math Model for Response of CID with Coil Spring Suspension

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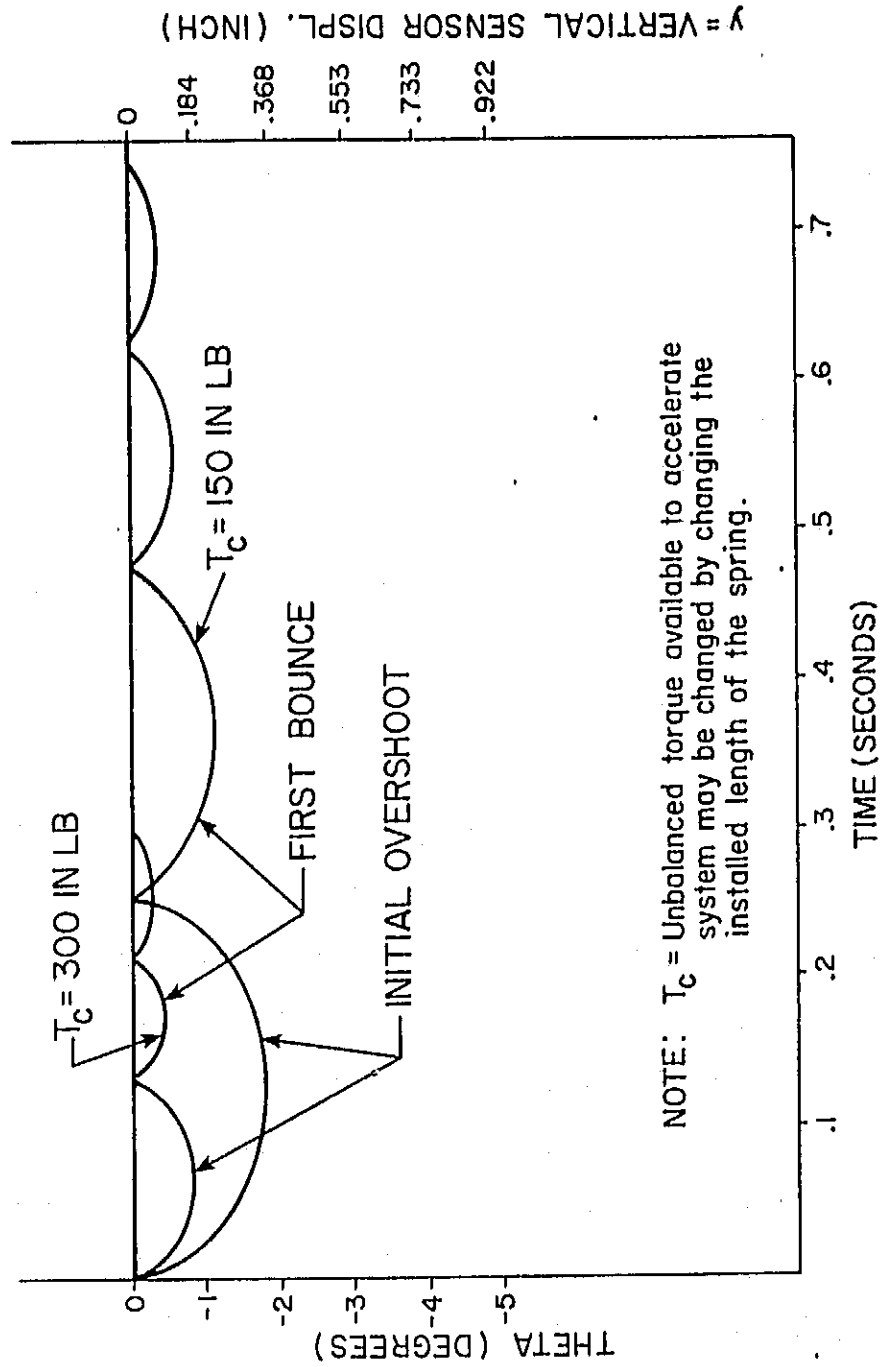


Figure B1.2. Response of CIS with Coil Spring Suspension When Moving Under A Downward Step in the Roof

APPENDIX C

LISTING OF LAYOUT NUMBERS WITH DESCRIPTION

NUMBER	DATE	DESCRIPTION
BJ00A	7-9-76	General arrangement of NCD with independent hydropneumatic suspension using one cylinder and a differential linkage
BJ001	8-20-76	General arrangement of NCD with non-independent coil spring suspension
BJ002	8-20-76	Detector housing
BJ003	8-26-76	Detector housing with explosion proof electronic box
BJ004	8-26-76	Nucleonic source housing with manual linkage for positioning the source
BJ005	11-5-76	Coil spring suspension system
BJ006	11-15-76	Bracket for scintillation detector
BJ007	11-22-76	Rubber boot for coil springs
BJ008	12-3-77	Shear pin and support brackets
BJ009	12-21-77	Hydraulic slave cylinder for positioning nucleonic source
BJ010	1-25-77	General arrangement of NCD with independent hydropneumatic suspension using two cylinders
BJ011	1-25-77	Detector housing with suspension linkage
BJ012	1-25-77	Nucleonic source housing with suspension linkage
BJ013	3-16-77	Shear pin and support brackets
BJ014	3-16-77	Accumulator mounting and support bars
BJ015	3-16-77	Hydraulic tubes
BJ016	3-16-77	Support bracket for suspension
BJ017	3-16-77	Nucleonic source with 4-bar linkage, automatic actuation system plus proximity switches for position identification

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OF POOR QUALITY

BJ018	2-28-77	Nucleonic source with cam for automatic actuation system
BJ019	3-9-77	General arrangement showing NCD with independent suspension system mounted on a LWS
BJ020	3-25-77	Bracket for scintillation detector
BJ021	3-6-77	Detector housing with explosion proof box
BJ022	3-13-77	Detector housing with electrical connectors
BJ-MB	4-16-77	Star wheel and mutilated gear concept for source actuation